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Müftü et al.

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[45] **Date of Patent:** **Nov. 21, 2000**

[54] **HELICAL SCAN RECORDING WITH A SELF-ACTING NEGATIVE AIR BEARING**

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[73] Assignee: **Massachusetts Institute of Technology**, Cambridge, Mass.

[21] Appl. No.: **09/347,978**

[22] Filed: **Jul. 6, 1999**

Related U.S. Application Data

[62] Division of application No. 08/815,194, Mar. 11, 1997.

[51] **Int. Cl.⁷** **G11B 5/53**

[52] **U.S. Cl.** **360/107**

[58] **Field of Search** 360/107, 130.23,
360/130.24

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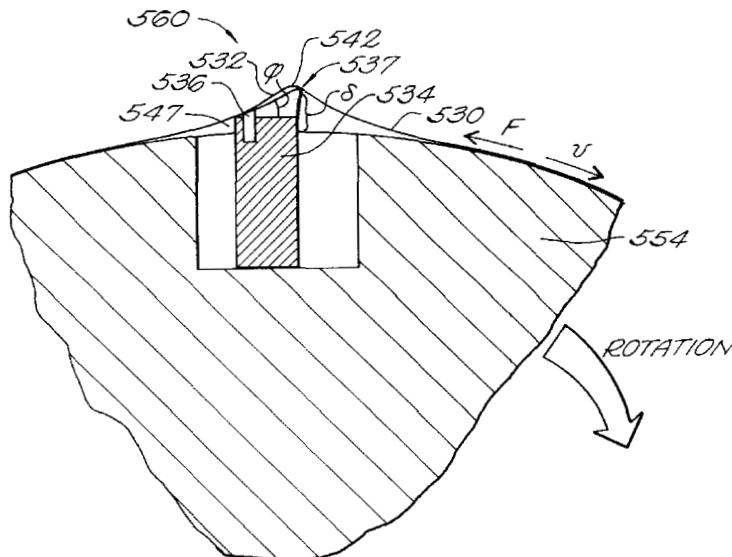
Primary Examiner—Robert S. Tupper

Attorney, Agent, or Firm—Steven J. Weissburg

[57] **ABSTRACT**

A flat head and a tape transport arrangement impart a wrap angle to the tape at the upstream corner of the head. The wrap angle, corner sharpness and tape stiffness are sufficient to cause a moving tape to form a hollow bump at the upstream corner, thereby creating a hollow into which entrained air can expand, causing a subambient pressure within and downstream of the bump. This pressure keeps the tape in contact with the head. It is created without the need for a groove or complex pressure relief slot(s). No contact pressure arises at the signal exchange site due to media wrap. The highest contact pressures are developed at a wrapped upstream corner. For a tape drive, traveling in both forward and reverse, the wrap can be at both the upstream and downstream (which is the “reverse upstream”) corners. Heads that are not flat can also be used, if the wrap angle relative to a main surface is sufficient and not too large. The wrapped head can also be used with rotating media, such as disks (floppy and hard) and rotating heads, such as helical wound heads for video recording. Multiple flat tape bearing surfaces can be separated by grooves and/or angles. Each flat can carry heads along one or more gap lines. Multiple adjacent narrow tracks can thus be written for extreme high track density recording.

10 Claims, 17 Drawing Sheets



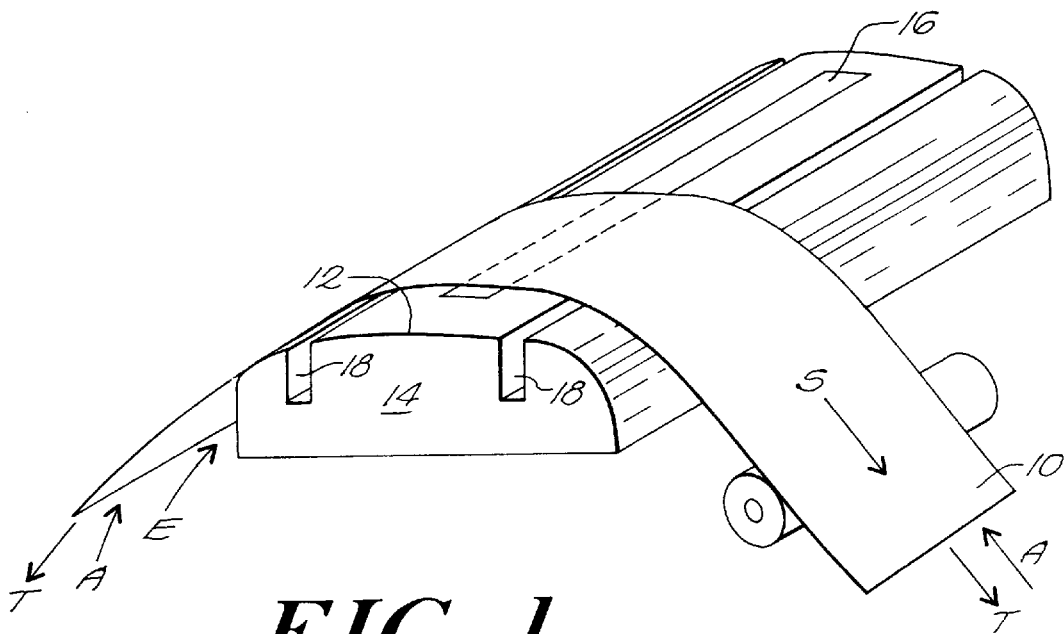


FIG. 1
(PRIOR ART)

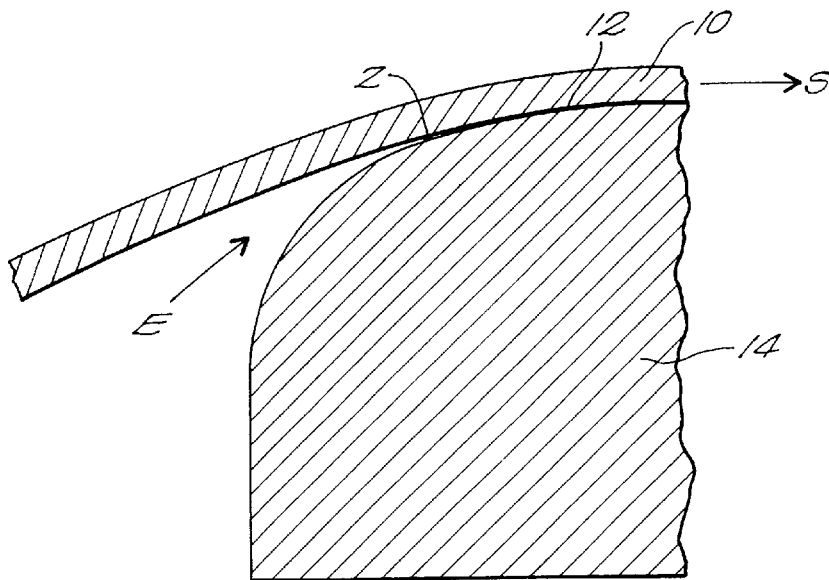


FIG. 1B
(PRIOR ART)

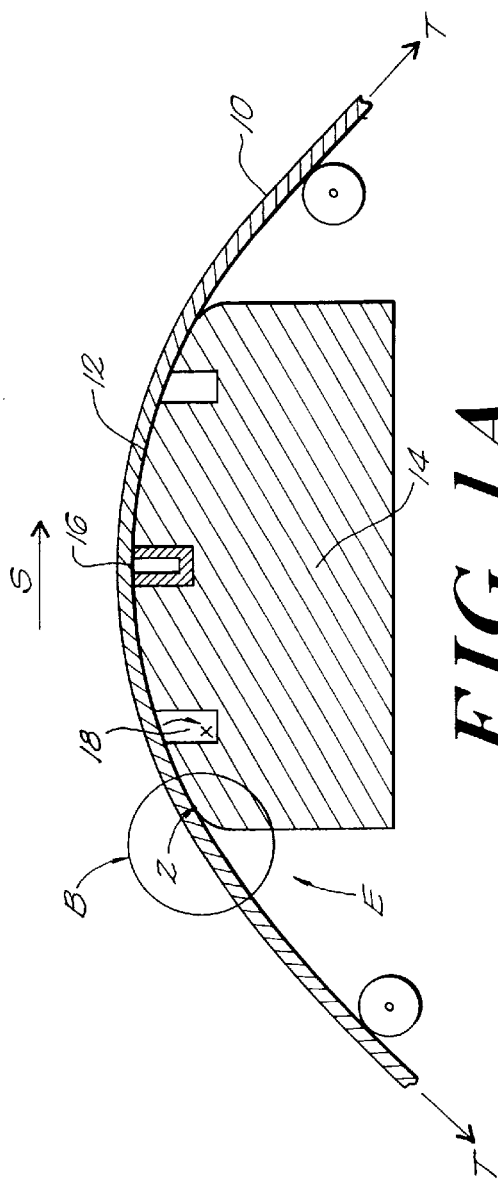


FIG. 1A
(PRIOR ART)

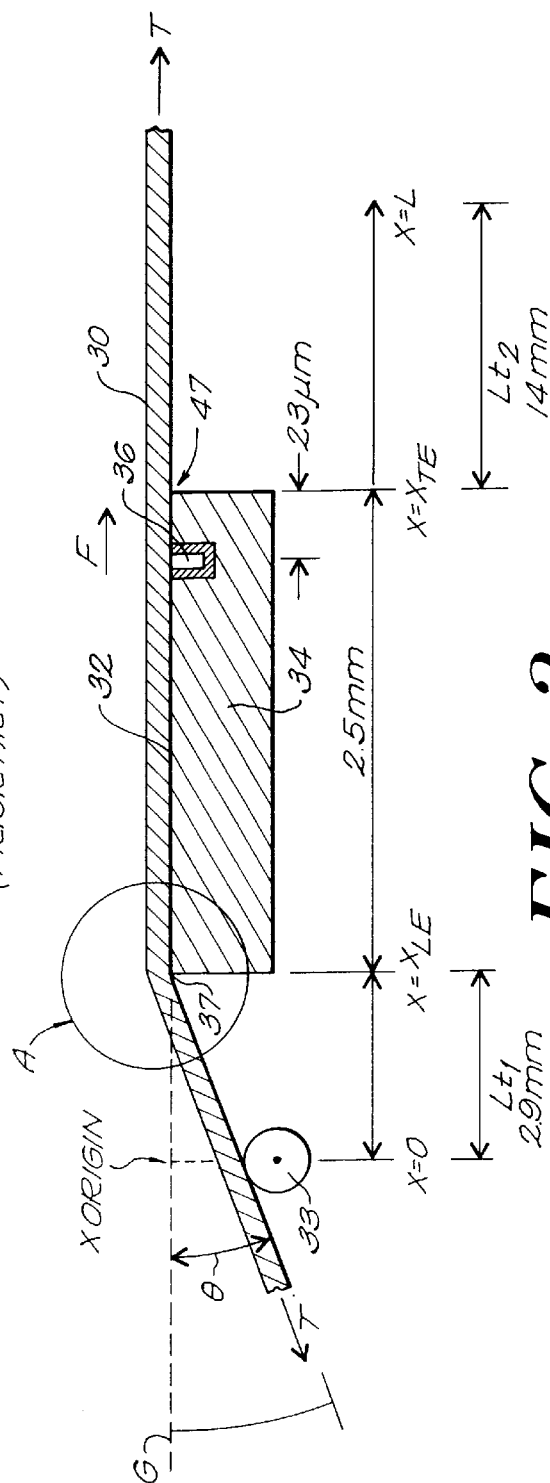


FIG. 2

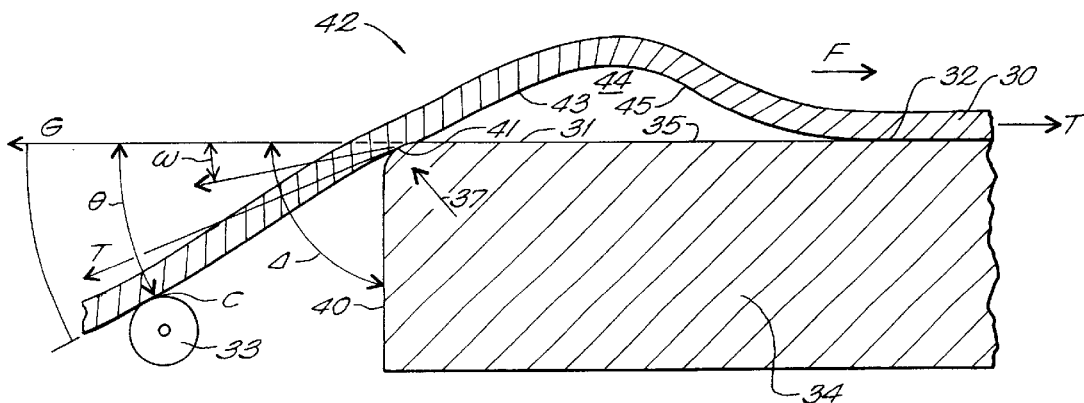


FIG. 2A

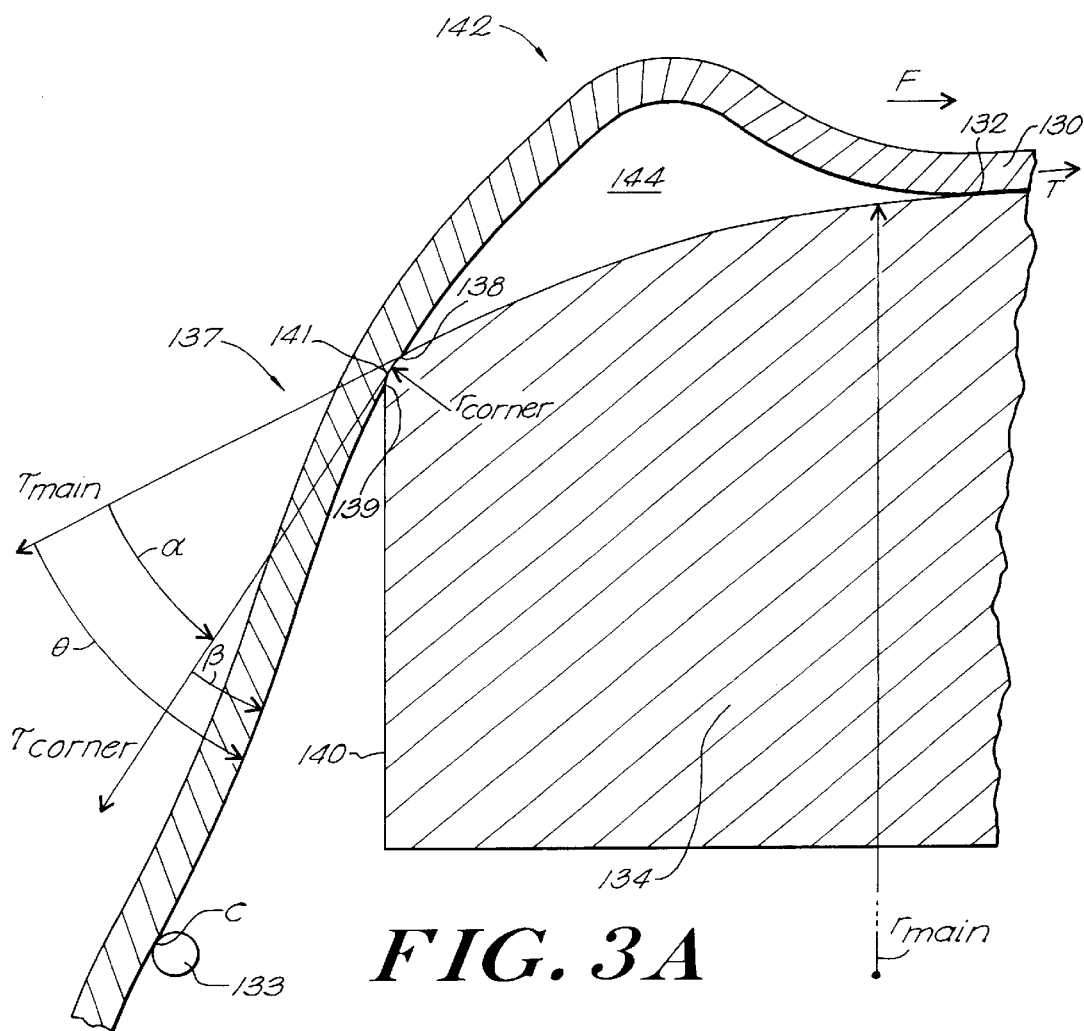


FIG. 3A

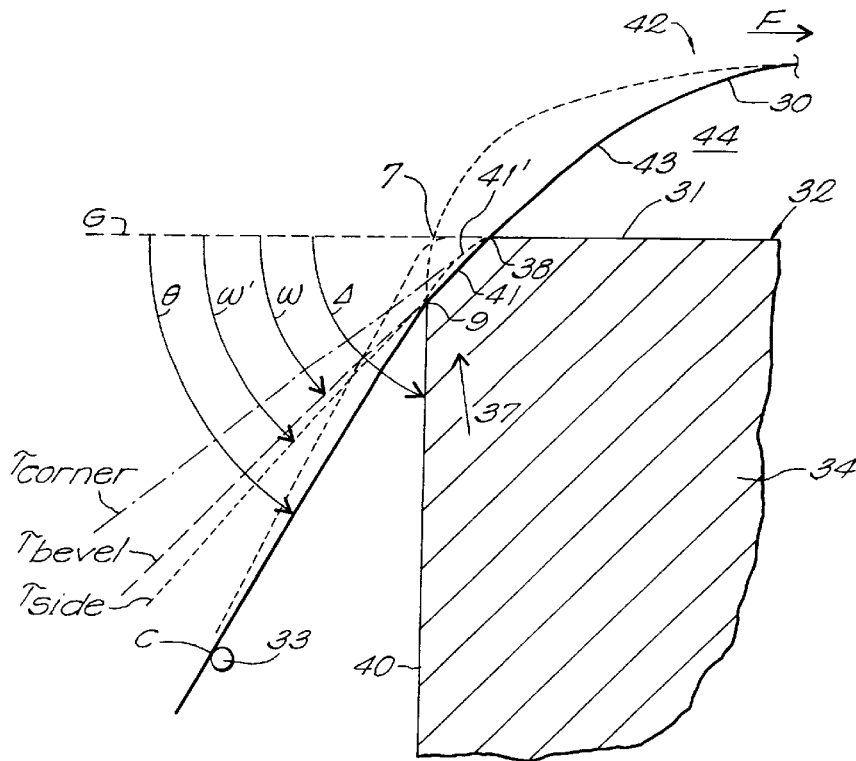


FIG. 2B

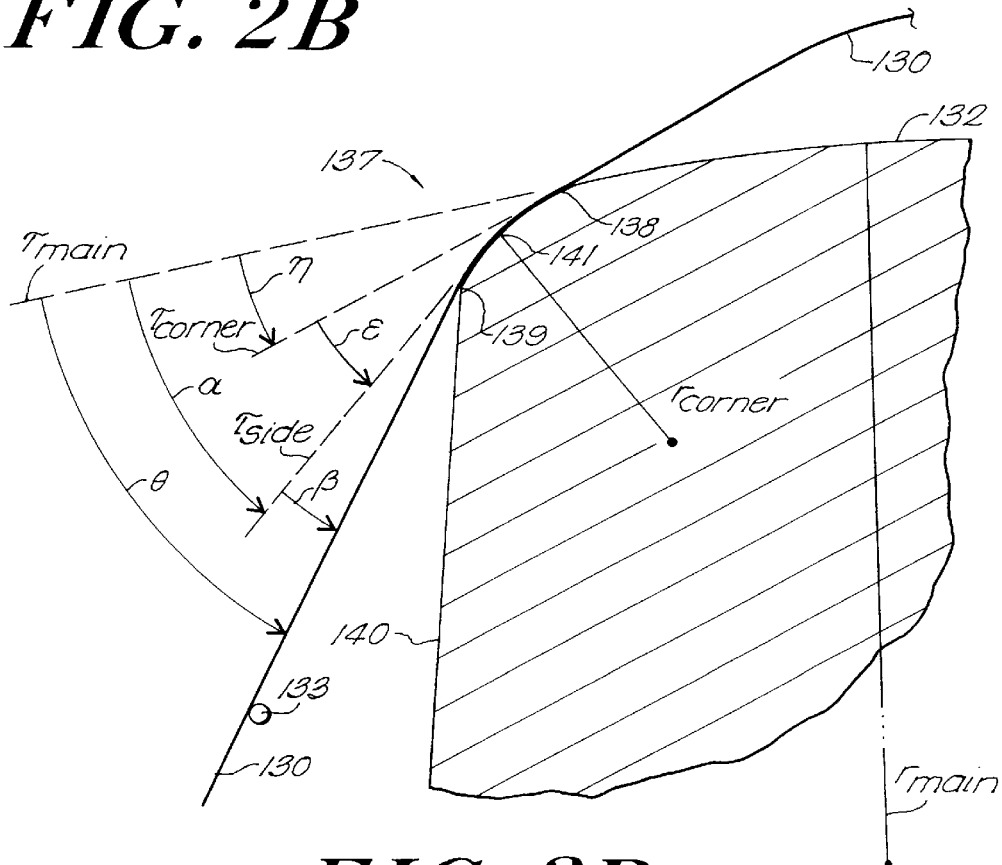
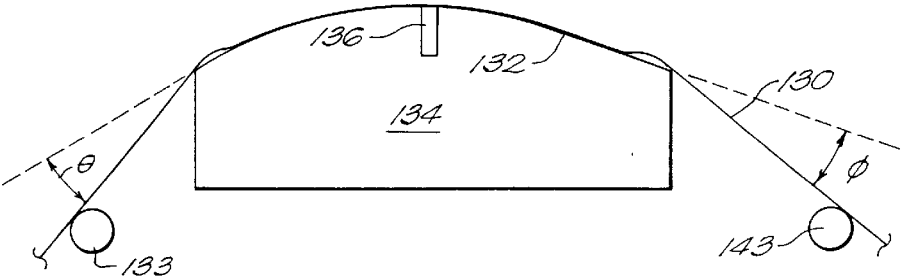
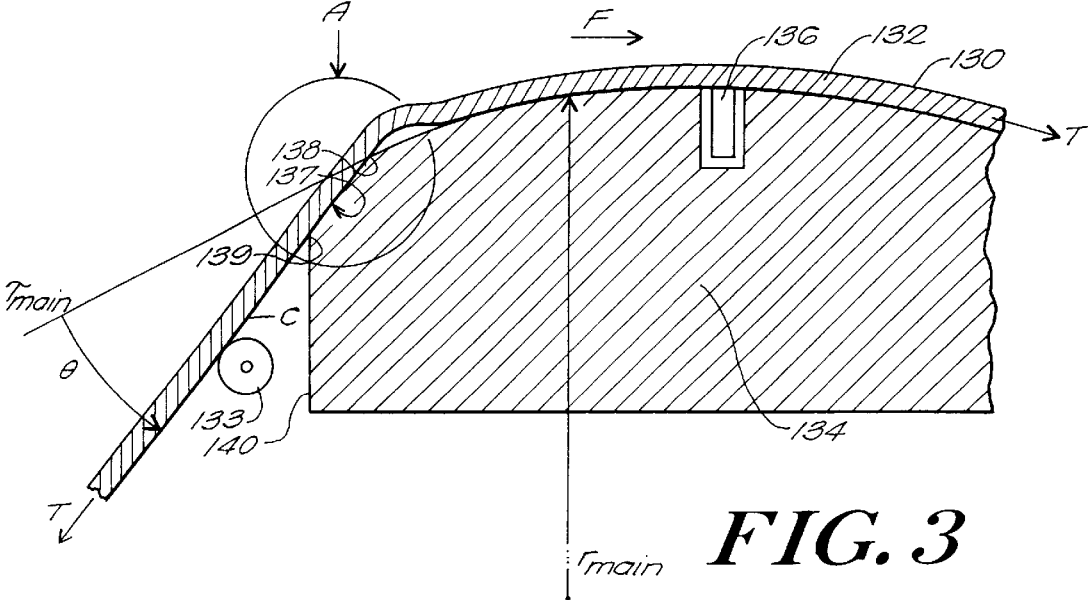


FIG. 3B



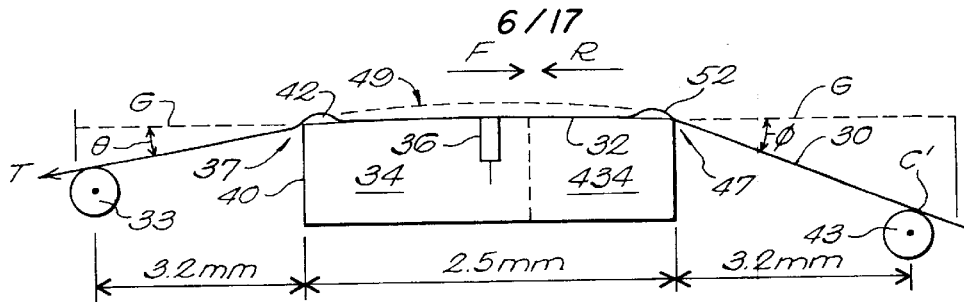


FIG. 4

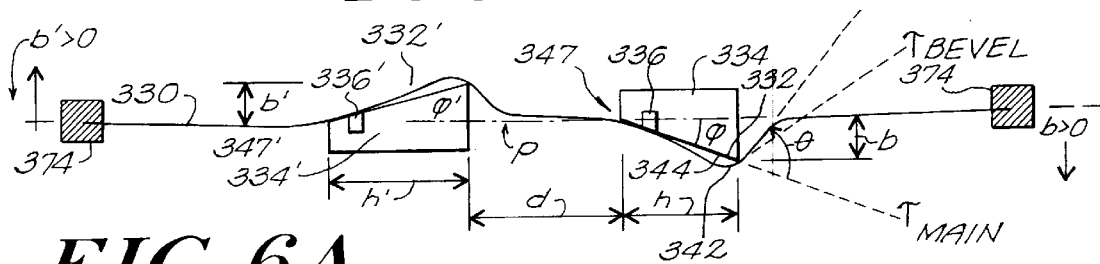


FIG. 6A

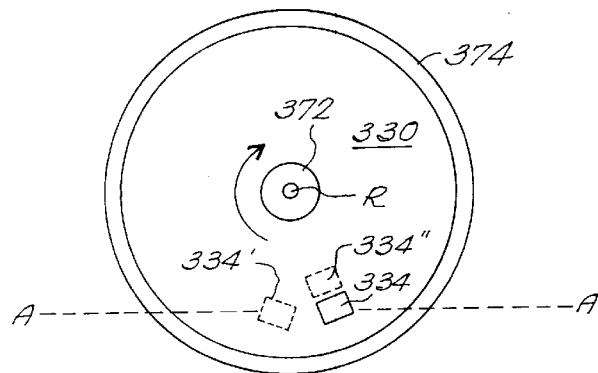


FIG. 6

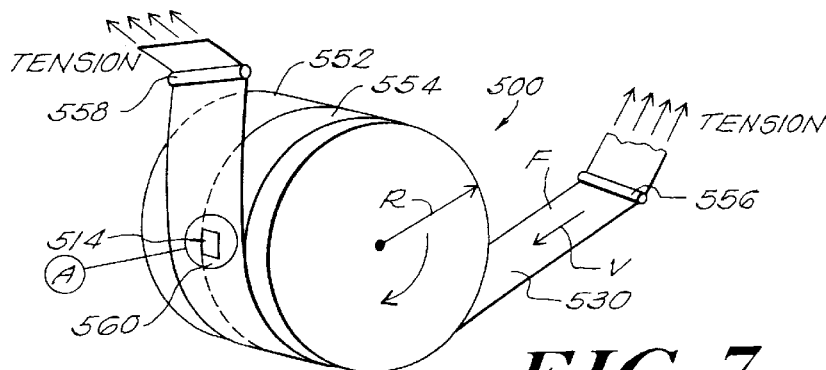
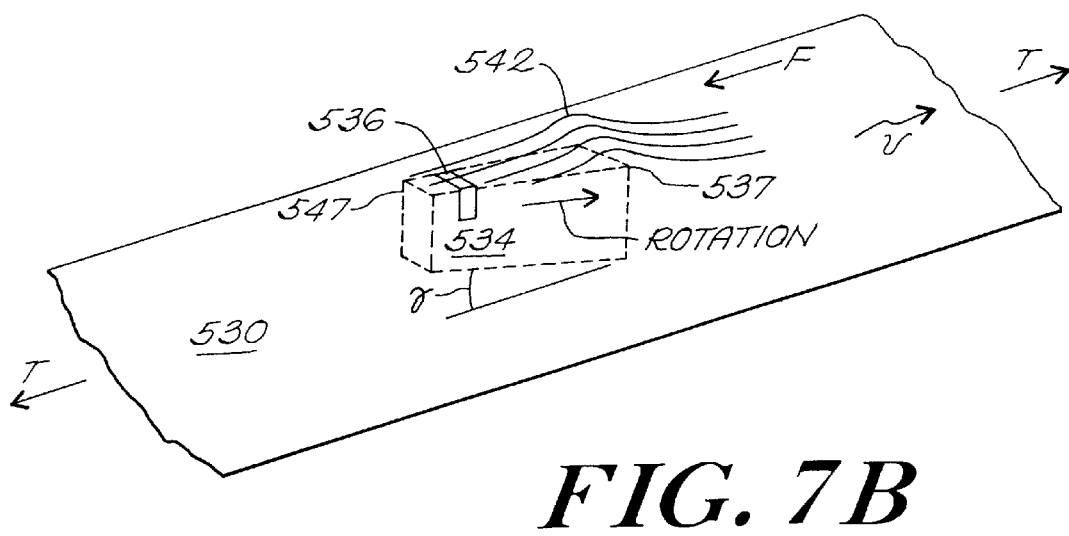
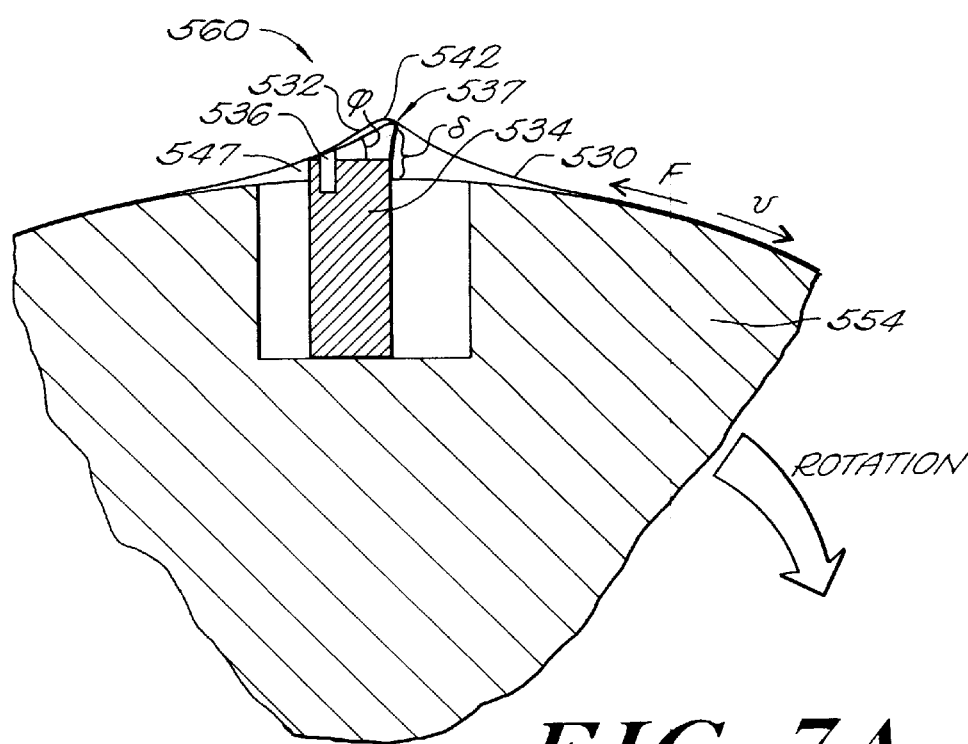


FIG. 7



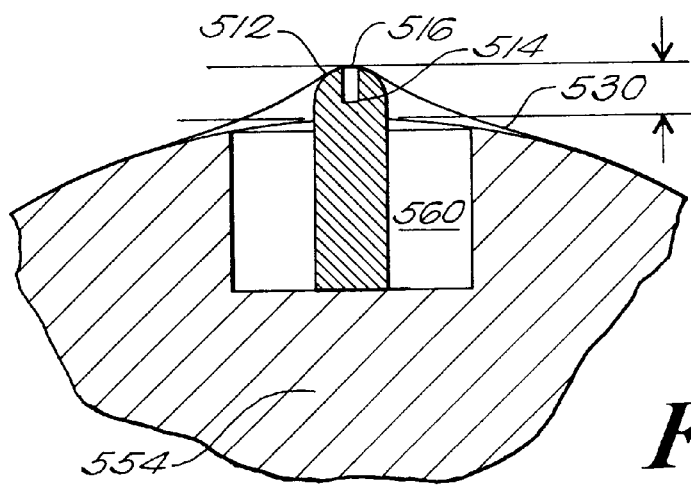


FIG. 7C
(PRIOR ART)

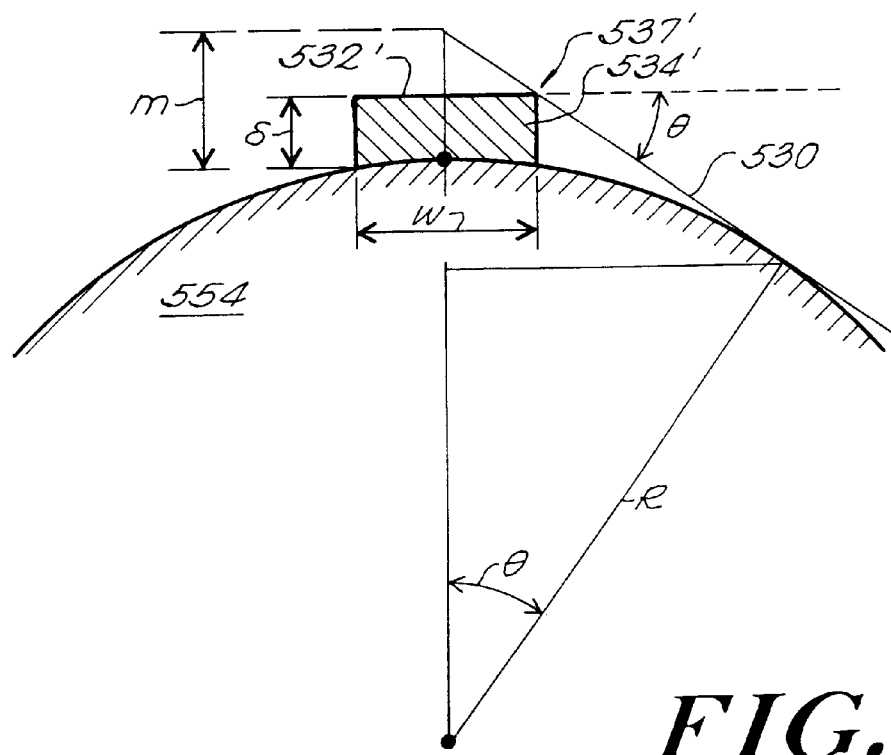


FIG. 7D

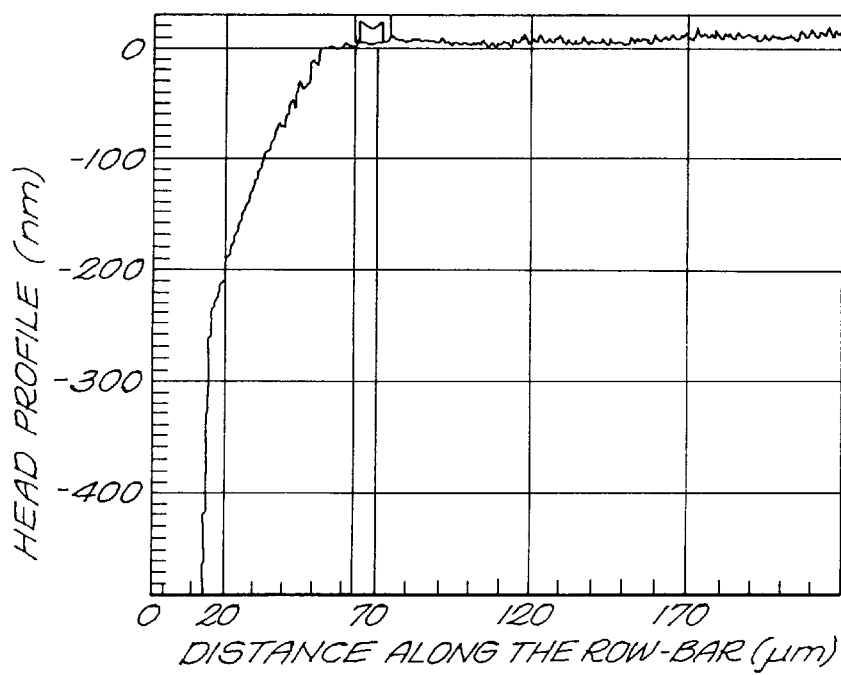


FIG. 8A

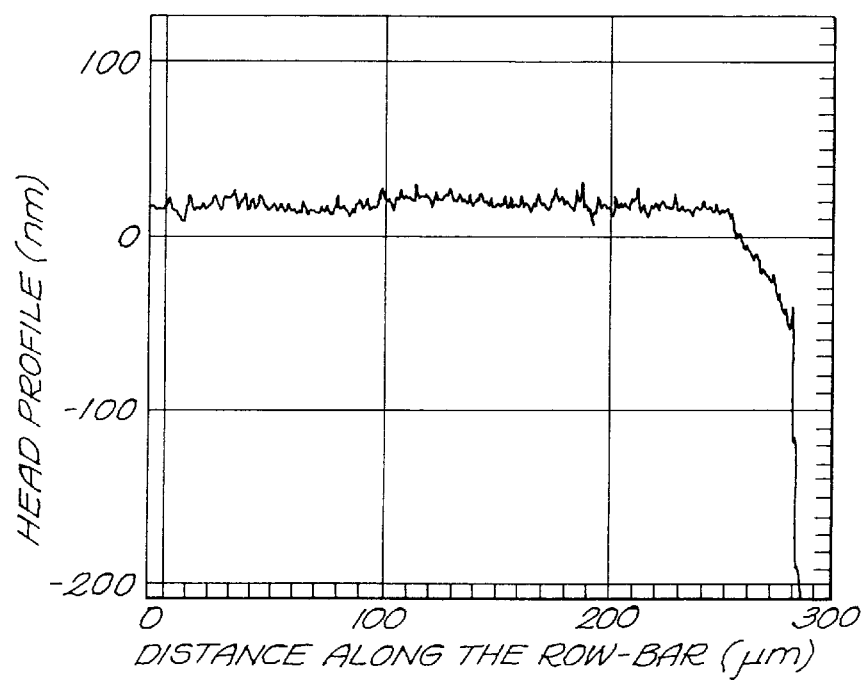


FIG. 8B

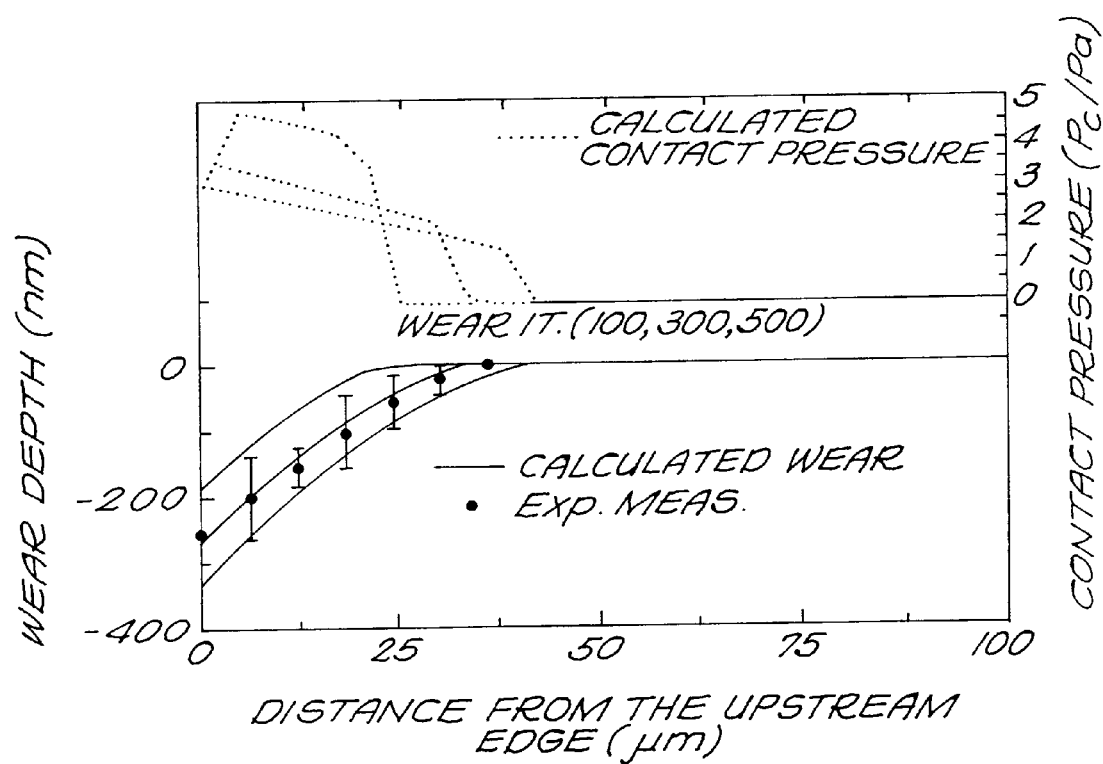


FIG. 9

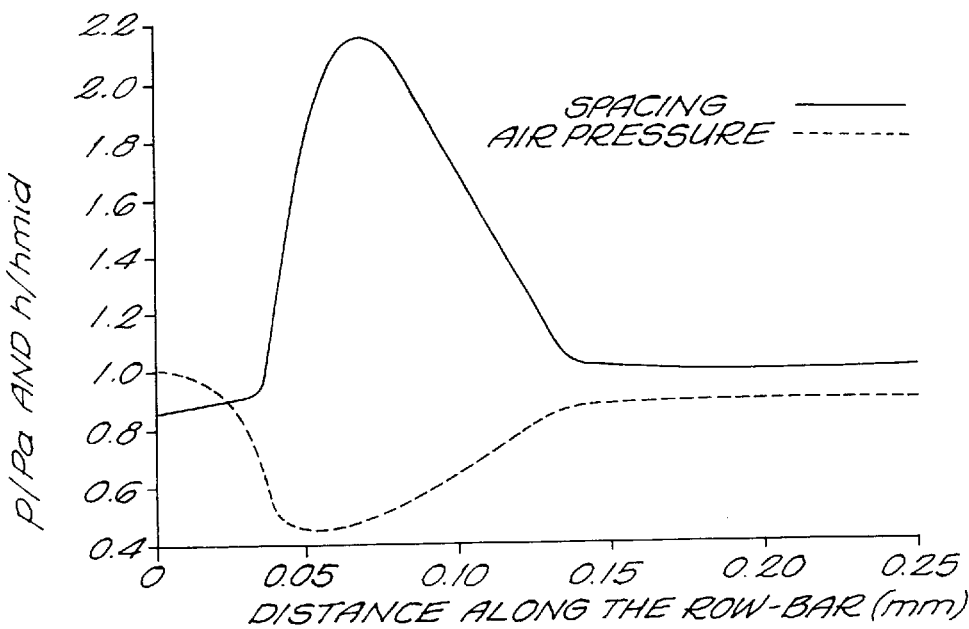


FIG. 10A

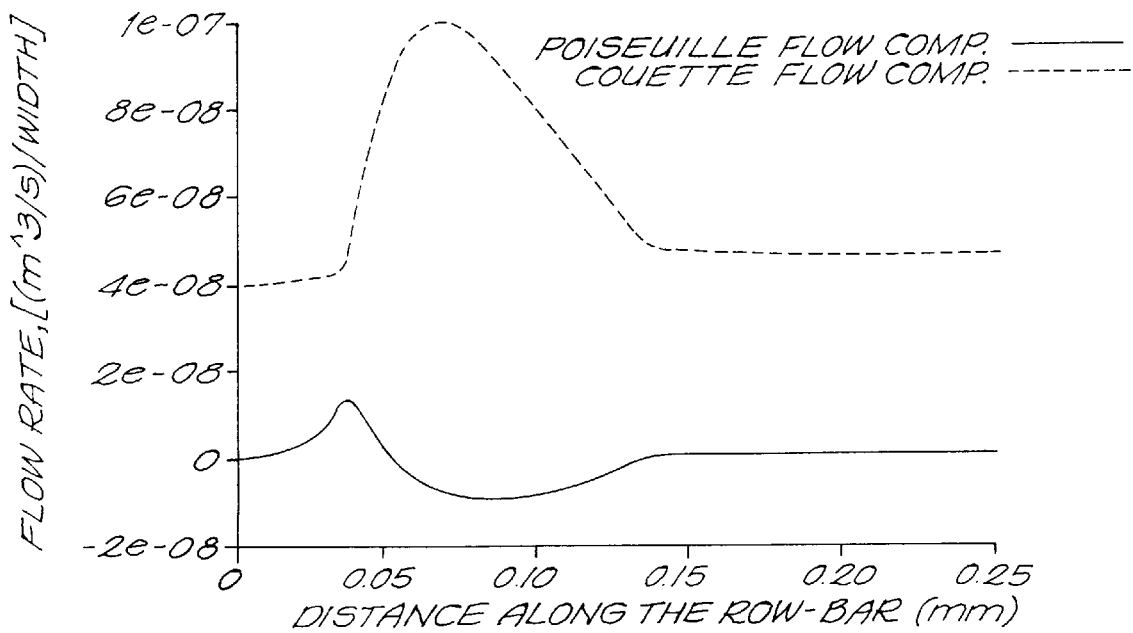


FIG. 10B

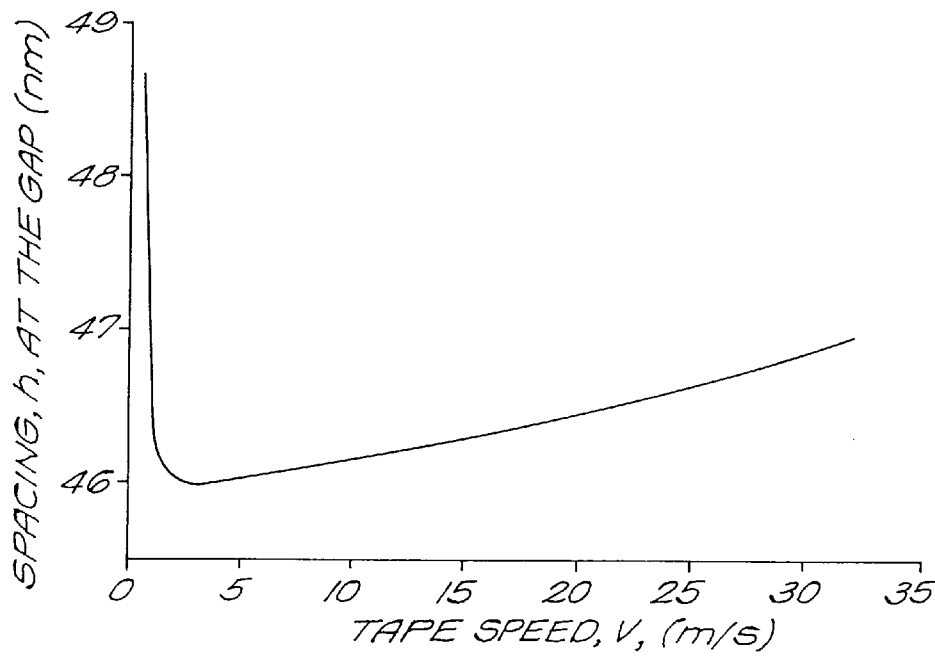


FIG. 11A

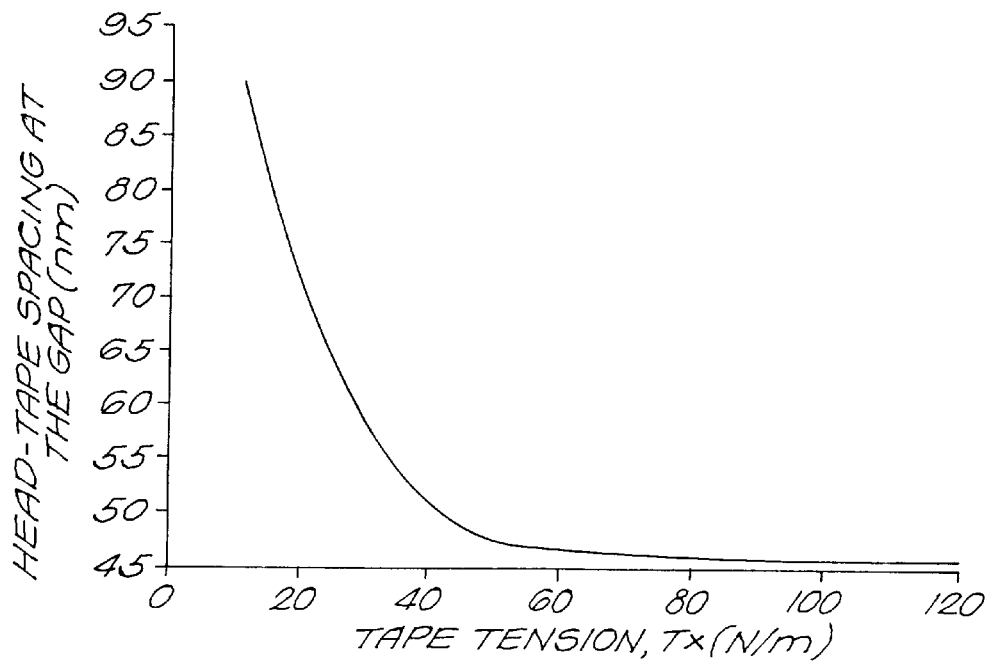
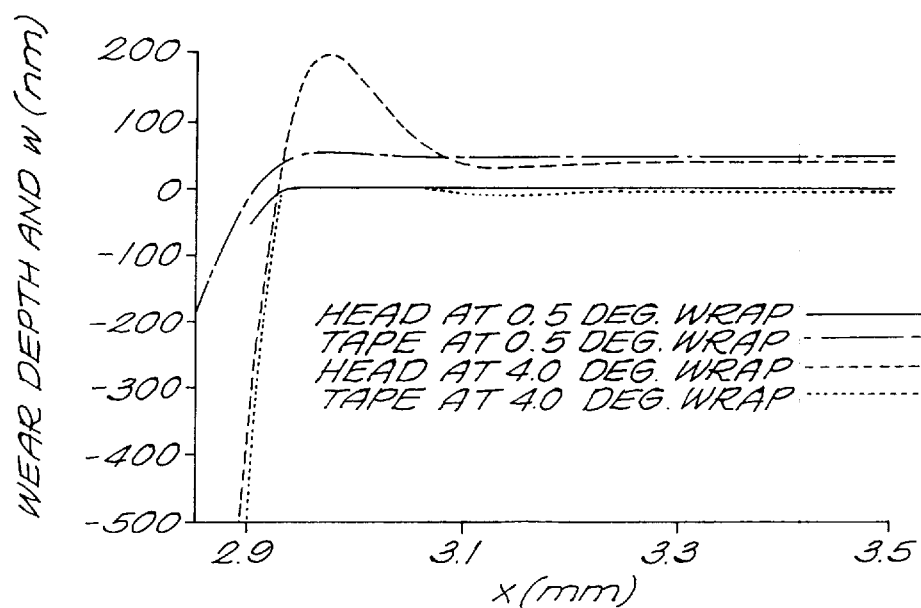
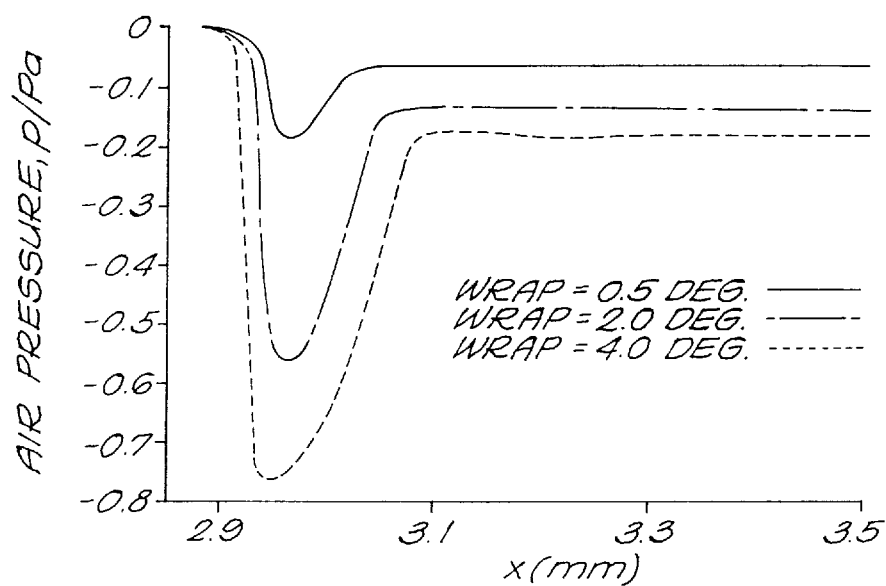


FIG. 11B

**FIG. 12A****FIG. 12B**

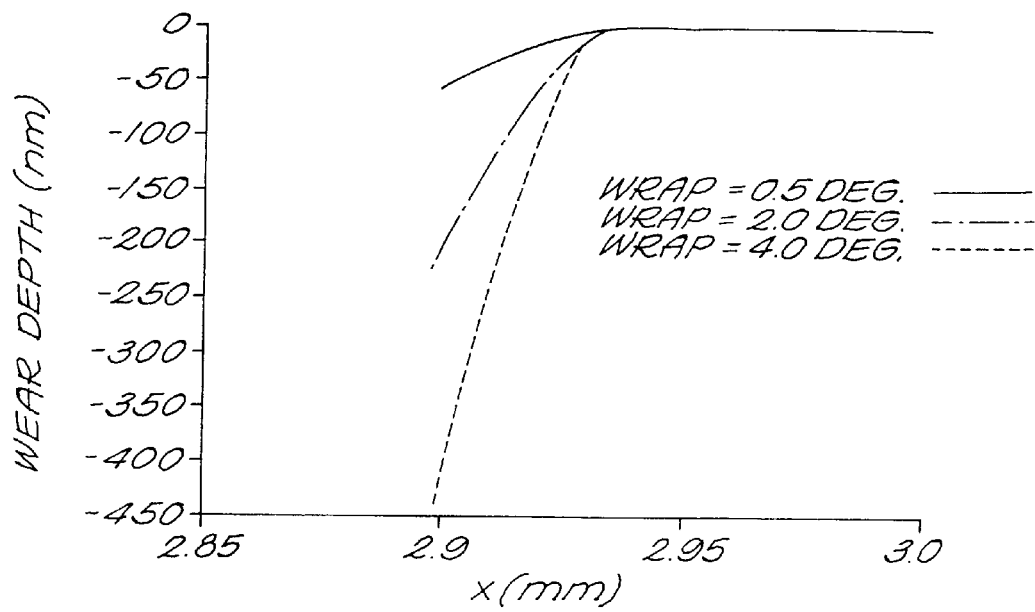


FIG. 13A

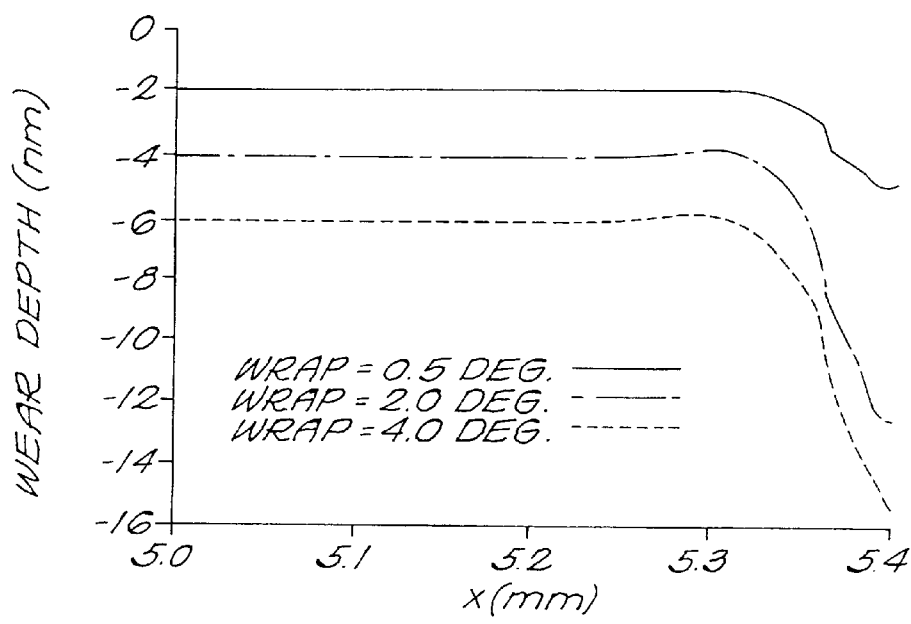


FIG. 13B

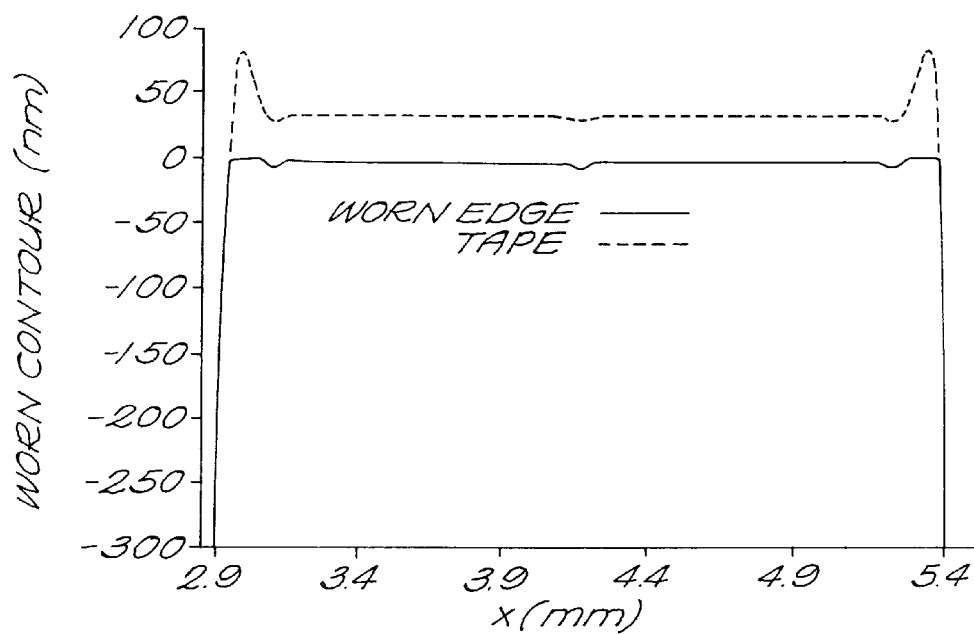


FIG. 14A

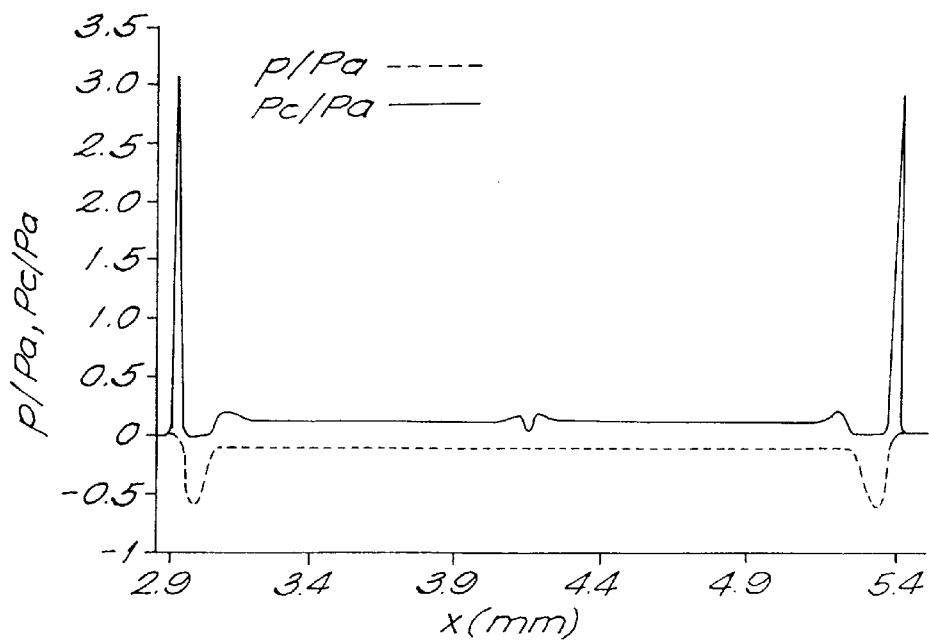


FIG. 14B

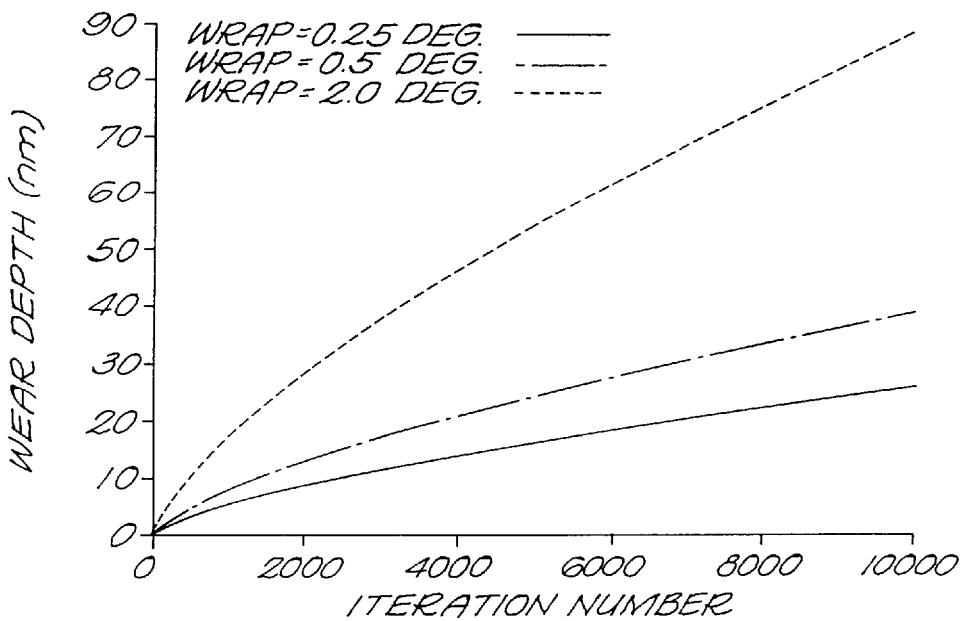


FIG. 15A

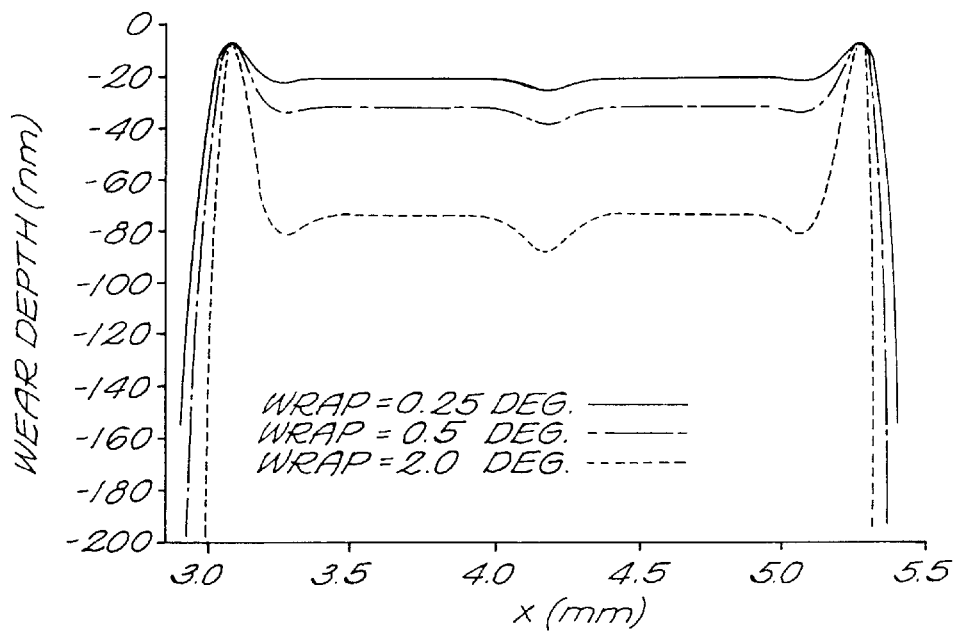


FIG. 15B

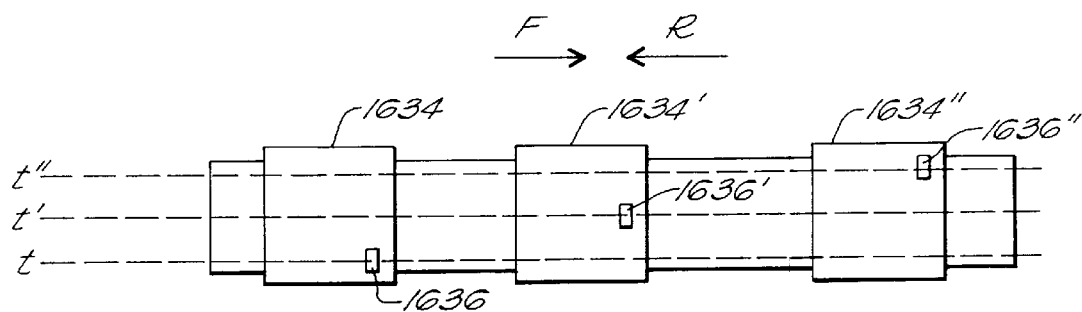


FIG. 16A

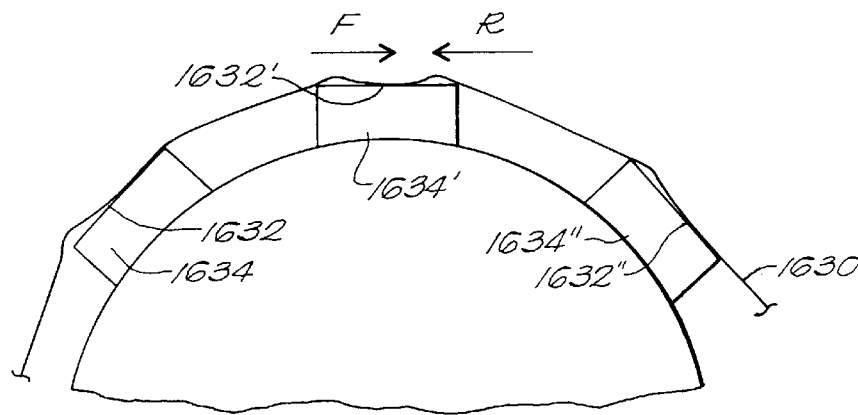


FIG. 16B

HELICAL SCAN RECORDING WITH A SELF-ACTING NEGATIVE AIR BEARING

This application is a divisional of application Ser. No. 08/815,194 filed Mar. 11, 1997 pending.

GOVERNMENT RIGHTS

This invention was made with government support under Contract Number NAS5-32353 awarded by NASA. The government has certain rights in the invention.

BACKGROUND

This invention relates generally to transport systems for sheetform media of magnetic and other types, and, more specifically, to an arrangement for enhancing contact at high speeds between a signal exchange head and a magnetic medium.

Increasing demands on data storage rates and capacities require modern tape drives to record in full contact between the head and the tape at relatively high speeds. In general, recording in contact minimizes losses due to the spacing between head and tape and enables higher recording densities (Hinteregger and Müftü). (This paper is incorporated fully by reference herein.) (A full citation to all references is at the end of this specification.) Contact is typically generated by wrapping a moving tape under tension over a curved geometry for the signal exchange surface. In such a situation, the contact pressure that arises is generally proportional to the ratio of the applied tension T to the radius of curvature R of the surface. Thus, increasing T and reducing R increases the contact pressure. Heads that are used for tape are typically made of a hard, ceramic material, and are designed to withstand the abrasive conditions of high speed tape use under such contact pressures.

Recording heads manufactured with the thin film (TF) semi-conductor technology are extensively used with magnetic hard disk media. These heads have signal processing properties that make them attractive for high speed, high signal density uses. However, at high contact pressures, thin film heads, just like ceramic heads made in conventional ways, experience head wear at the signal exchange site and recession at the magnetic poles, which can become a problem. Thin-film heads typically tolerate less than $1\text{ }\mu\text{m}$ wear and 30 nm of recession. Wear resistant head materials and tape bearing surface overcoats can improve the head's wear life. Wear rate tends to be inversely proportional to the hardness of the material (Bhushan and Lowry; Kawakubo and Yahisa) and proportional to contact pressure. But experiments show that wear is not proportional to contact pressure and is sublinear at sufficiently low Contact pressures (Bhushan Handbook). Therefore, the design of a contact-recording-head should include a hard load bearing surface, and guarantee contact pressures consistent with preventing separation of the tape from the head, and low enough to provide an acceptable head life (if not to arrest wear completely).

Some geometries, such as are shown schematically in FIGS. 1, 1A and 1B, promote what is known as "self-lubrication." As shown in FIG. 1B, the curvature of the signal exchange surface 12 is smoothly continuous, with no slope discontinuities. In other words,

$$\frac{d^2\delta}{ds^2}$$

is continuous, where δ is the mathematical function describing the head and s is the coordinate axis along the head. The tape is typically wrapped around the head so that it follows the tangent to the surface at the point Z of separation. Such a wrapping is referred to herein as a "tangential wrap".

The tape and the unwrapped part of the surface form a gently converging channel, such that a relatively large volume of air is entrained therebetween. Air that is entrained at E between the tape 10 moving in the direction S and the signal exchange surface 12 of the head 14 forms a cushion that separates the two from each other over large extents of the head. When this occurs, it is said that the tape "flies". This is undesirable, as increases in the distance between the tape and the magnetic gap at the signal exchange site 16 cause exponential decreases in the strength of the read back signal. According to the Wallace equation, approximately 55 dB per wavelength Λ of the recorded signal is lost as a result of this distance increase. The separation shown in FIG. 1B is greatly exaggerated. An actual spacing of only $0.18\text{ }\mu\text{m}$ is enough to reduce the amplitude of a recording with a wave length of $1\text{ }\mu\text{m}$ by a factor of ten.

Although separation of the tape from the head due to the self-lubricating effects of entrained air ("flying") is, in general, undesirable, it is also undesirable to apply a large tension to the moving tape to dramatically overcome this air lubrication effect, because that may result in higher undesirable head wear rate, discussed above. Wear would be a particularly significant problem with relatively soft thin film layers. What is desired is to achieve a balance of the two effects: making sure that the tape would always be in contact with the head, with a minimal amount of contact pressure.

One known way to help to balance these effects is to introduce one or more grooves or relieved areas 18 into the head material, near to the upstream corner. As shown FIG. 1A, the entrained air is gradually compressed as it is drawn along between the tape 10 and the signal exchange surface 12 of the head 14, and expands into the cavity 18 shown at the arrow x . This expansion results in a reduction in pressure, sometimes even to a level below ambient, so that the net total pressure on the tape 10 downstream of the cavity 18, due to the surrounding air, is toward the head surface 12. The effect of this reduced pressure lessens as the distance downstream from the cavity 18 increases, and in some cases, additional grooves are used.

The use of such a groove provides the opportunity for more control over the balancing of the air and tension related contributions to the contact pressure between the tape and the head at different locations along the dimension of tape travel. However, radius lapping in particular, and to a lesser extent machining grooves, in the very hard materials used for modern heads, is difficult and costly.

In thin film heads, the signal exchange elements are made of layers that must have a certain minimum thickness to function. These layers must also be a certain minimum distance away from the main surface of the head, where the tape or other medium contacts it. Further, with curved surface heads, the surface must be machined (sometimes lapped) to a precise shape. However, as the surface is formed by removing surface material, it is difficult to achieve the required surface, while also maintaining the required thickness of the signal exchange elements, as they might be inadvertently removed during the shaping process. Further, if excessive material is removed during the shaping process,